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Cold Stress

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COLD STRESS

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Canadian Centre for Occupational Health and Safety

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COLD STRESS

This publication provides a basic understanding of occupational cold stress and recommends ways of protecting against its harmful effects. It was prepared as a source of information for health and safety committees and others with an interest in understanding and reducing the occupational risk of cold stress.

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INTRODUCTION

Stress is a physical, chemical or emotional factor that causes bodily or mental strain and may result in disease. Stress can be caused by many factors including cold. Workers at risk of suffering cold stress include:

- outdoor workers
- workers in refrigerated warehouses
- meat packaging and meat storage workers
- fishermen
- divers

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1. COLD ENVIRONMENTS AND THE HUMAN BODY

Most people feel comfortable when the air temperature ranges from 18°C to 22°C and the relative humidity is about 45 percent. Under these circumstances, heat production inside the body equals the heat loss from the body, and the internal body temperature is kept around 37°C. For constant body temperature, even under changing environmental conditions, rates of heat gain and heat loss should balance.

Heat production

Every living organism produces heat. In cold weather the only source of heat gain is the body's own internal heat production, which increases with physical activity. Hot drinks and food are also a source of heat.

Heat loss

The body loses heat to its surroundings in several different ways. Heat loss is greatest if the body is in direct contact with cold water. The body can lose 25 to 30 times more heat when in contact with cold wet objects than under dry conditions or with dry clothing. The higher the temperature differences between the body surface and cold objects, the faster the heat loss.

Heat is also lost from the skin by contact with cold air. The rate of loss depends on the air speed and the temperature difference between the skin and the surrounding air. At a given air temperature, heat loss increases with air speed. Sweat production and its evaporation from the skin is also a cause of heat loss. This is important when performing hard work.

Small amounts of heat are lost when cold food and drink are consumed. As well, heat is lost during breathing by inhaling cold air, and through evaporation of water from the lungs.

Maintaining heat balance

The body maintains heat balance in two ways:

By reducing the amount of blood circulating through the skin and outer body parts. This minimizes cooling of the blood by shrinking the diameter of blood vessels. At extremely low temperatures, loss of blood flow to the extremities may cause an excessive drop in tissue temperature, resulting in damage such as frostbite.

By shivering, which increases the body's heat production. This provides a temporary tolerance for cold but cannot be maintained for longer periods.

2. HEALTH EFFECTS OF COLD STRESS

Overexposure to cold causes discomfort and a variety of health problems.

Effect on performance

Cold stress impairs performance of both manual and complex mental tasks. Sensitivity and dexterity of fingers lessen in cold. At lower temperatures still, cold affects deeper muscles, resulting in reduced muscular strength and stiffened joints. Mental alertness is reduced due to cold-related discomfort. For all these reasons accidents are more likely to occur in very cold working conditions.

Cold injuries

The main cold injuries are frostnip, frostbite, immersion foot and trenchfoot, which occur in localized areas of the body.

Frostnip is the mildest form of cold injury. It occurs when ear lobes, noses, cheeks, fingers, or toes are exposed to cold. The skin of the affected area turns white. Frostnip can be prevented by warm clothing and is treated by simple rewarming.

Frostbite is a common injury caused by exposure to extreme cold or contact with extremely cold objects. It occurs when tissue temperature falls below the freezing point. Blood vessels may be severely and irreparably damaged, and blood circulation may stop in the affected tissue. In mild cases, the symptoms include inflammation of the skin in patches, accompanied by

slight pain. In severe cases, there could be tissue damage without pain, or there could be burning or prickling sensations resulting in blisters. Frostbitten skin is highly susceptible to infection, and therefore gangrene.

In case of suspected frostbite the body should be slowly warmed to normal temperature. Frostbitten limbs should be warmed first in cold water at 10°C to 15°C. Water temperature should increase by 5°C every 5 minutes to a maximum of 40°C. Complete recovery takes several days. Residual effects such as cold feet, numbness, abnormal skin colour and pain in joints may continue for several days, especially in winter.

Immersion foot occurs in individuals whose feet have been wet, but not freezing cold, for days or weeks. The primary injury is to nerve and muscle tissue. Symptoms are numbness, swelling or even superficial gangrene.

Trenchfoot is "wet cold disease" resulting from exposure to moisture at or near the freezing point for one to several days. Symptoms are similar to immersion foot--swelling and tissue damage.

Hypothermia

In moderately cold environments, the body's core temperature does not usually fall more than 1°C to 2°C below the normal 37°C because of the body's ability to adapt. However, in intense cold without adequate clothing, the body is unable to compensate for the heat loss, and the body's core temperature starts to fall. The sensation of cold, followed by pain, in exposed parts of the body is the first sign of cold stress. The most dangerous situation occurs when the body is immersed in cold water.

As the cold worsens or the exposure time increases, the feeling of cold and pain starts to diminish because of increasing numbness (loss of sensation). If no pain can be felt, serious injury can occur without the victim noticing.

Next, muscular weakness and drowsiness are experienced. This condition is called hypothermia and usually occurs when body temperature falls below 33°C. Additional symptoms of hypothermia include interruption of shivering, diminished consciousness and dilated pupils. When body temperature reaches 27°C, coma (profound unconsciousness) sets in. Heart activity stops around 20°C and the brain stops functioning around 17°C.

The hypothermia victim should be immediately warmed, either by being moved to a warm room or by the use of blankets. Rewarming in water at 40°C to 42°C has been recommended in cases where hypothermia occurs after the body was immersed in cold water.

Response in men and women

Studies have shown that response to cold stress in women could differ from that of men in several respects. The rate of cooling of the body core is slower in women. However, in general, women have less capacity for metabolic heat production by either exercise or shivering. In addition, the rate of cooling of the extremities (feet, hands) is faster among women.

As a result of these differences, women are generally at a greater risk of cold injury.

Predisposing conditions

Susceptibility to cold injury varies from person to person. In general, people in good physical health are less susceptible to cold injury. Conditions which worsen the risk of cold injury are listed below.

- Old age
- Diseases of the blood circulation system
- Previous cold injury
- Raynaud's disease
- Fatigue
- Consumption of alcohol or nicotine
- Use of certain drugs or medication
- Injuries resulting in blood loss or altered blood flow

3. ACCLIMATIZATION TO COLD

Although people easily adapt to hot environments, they do not acclimatize well to cold. However, frequently-exposed body parts can develop some degree of tolerance to cold. Blood flow in the hands, for example, is maintained in conditions which would cause extreme discomfort and loss of dexterity in unacclimatized persons. This is noticeable among fishermen who are able to work with bare hands in extremely cold weather.

4. WORKPLACE CONDITIONS THAT INFLUENCE COLD STRESS

The severity of cold stress depends on the air temperature, wind speed, and intensity of physical activity. The levels of these factors are determined as follows.

Air temperature

Air temperature is measured by an ordinary thermometer in degrees Celsius (°C).

Wind speed

Different types of commercially-available anemometers are used to measure wind speed or air movement. These are calibrated in meters per second (m/s), kilometres per hour (km/h) or miles per hour (mph). Air movement is usually measured in m/s, while wind speed is usually measured in km/h or mph. The following is a suggested guide for estimating wind speed if accurate information is not available:

- 8 km/h (5 mph) : light flag moves,
- 16 km/h (10 mph): light flag fully extended,
- 24 km/h (15 mph): raises newspaper sheet,
- 32 km/h (20 mph): causes blowing and drifting snow.

Physical activity

The production of body heat by physical activity (metabolic rate) is difficult to measure. However, tables are available showing metabolic rates for a variety of activities (Coble, 1979). Metabolic heat production is measured in kilocalories (kcal) per hour. One kilocalorie is the amount of heat needed to raise the temperature of one kilogram of water by 1°C.

Wind-chill temperature

At any temperature one feels colder as the wind speed increases. The combined effect of cold air and wind speed is expressed as "equivalent chill temperature" (ECT) or simply, wind-chill temperature in degrees Celsius or Fahrenheit (see Appendix A). This is essentially the air temperature that would produce the same cooling effect on exposed human flesh as the given combination of air temperature and wind speed. It is used for determining clothing requirements and the possible health effects of cold.

Figure 1 provides a simple representation of the levels of hazard for different air temperatures and wind speeds.

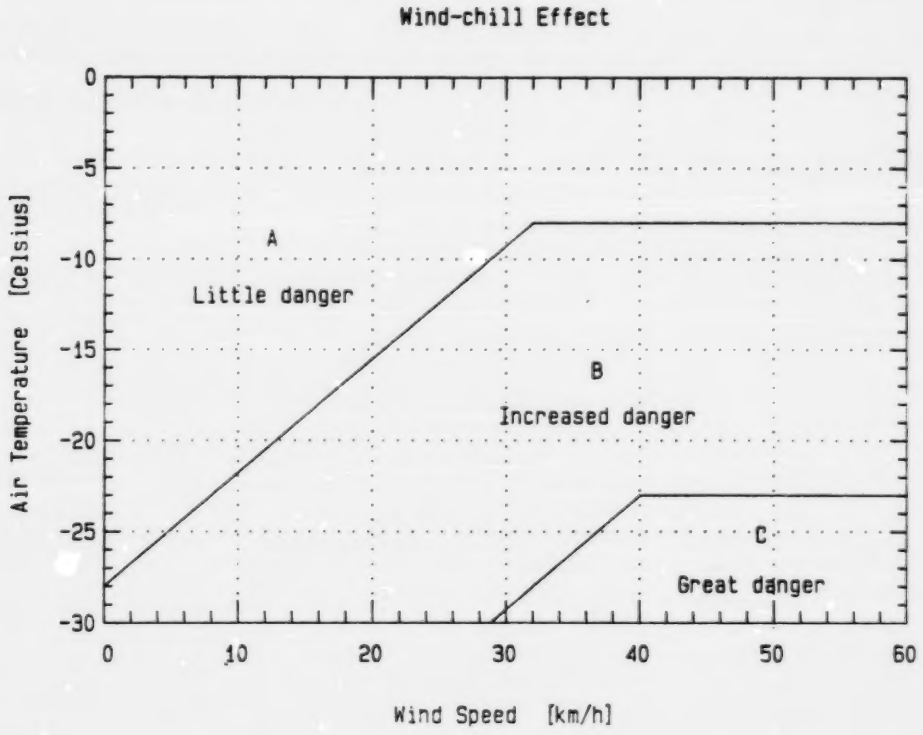

Figure 1 - Various degrees of hazard for different air temperatures and wind speeds

The figure is divided into three areas:

AREA A: There is little danger for dry skin exposed for less than one hour to the indicated air temperatures and wind speeds. However, there is great danger of having a false sense of security.

AREA B: There is increasing danger of freezing of exposed flesh within one minute.

AREA C: There is great danger since flesh may freeze within 30 seconds.

Note: Wind speeds greater than 60 km/h (38 mph) have little additional effect. Also, trenchfoot and immersion foot may occur at any point in the graph.

5. EXPOSURE LIMITS

In Canada, there are no maximum exposure limits for cold working environments. The "work warm-up schedule," developed by the Saskatchewan Department of Labour, has been adopted by the American Conference of Governmental Industrial Hygienists (ACGIH) as Threshold Limit Values (TLVs). Details can be found in Appendix B.

6. PREVENTION AND CONTROL

For continuous work in temperatures below the freezing point, heated warming shelters such as tents, cabins and rest rooms should be made available. The pace of work should not be so heavy as to cause excessive sweating. If such work is necessary, proper rest periods in a warm area should be allowed for changing into dry clothes. New employees should be given enough time to get accustomed to cold and protective clothing before assuming a full work load.

The risk of cold injury can be minimized by proper equipment design, protective clothing and safe work practices. The following is a summary of actions recommended by the ACGIH.

Equipment design

For work below the freezing point, metal handles and bars should be covered by thermal insulating material. Also, machines and tools should be designed so that they can be operated without having to remove mittens.

Clothing

Protective clothing is needed for work at or below 4°C. Clothing should be selected to suit the cold, level of activity and job design.

Clothing should be worn in multiple layers which provide better protection than a single thick garment. The layer of air between clothing provides better insulation than the clothing itself. In extremely cold conditions, where face protection is used, eye protection must be separated from respiratory channels (nose and mouth) to prevent exhaled moisture from fogging and frosting eye shields.

For work in wet conditions, the outer layer of clothing should be waterproof. If the work area cannot be shielded against wind, an easily removable windbreak garment should be used. Under extremely cold conditions, heated protective clothing should be made available.

Clothing should be kept clean, since dirt fills air cells in fibres of clothing and destroys its insulating ability.

Clothing must be dry. Moisture should be kept off clothes by removing snow prior to entering heated shelters. While the worker is resting in a heated area, perspiration should be allowed to escape by opening the neck, waist, sleeves and ankle fasteners.

If fine manual dexterity is not required, gloves should be used below 4°C for light work and below -7°C for moderate work. For work below -17°C, mittens should be used. Felt-lined, rubber bottomed, leather-topped boots with removable felt insoles are best suited for heavy work in cold.

Almost 50 percent of body heat is lost through the head. A wool knit cap or a liner under a hard hat reduces excessive heat loss.

Prevention

The contact of bare skin with cold surfaces (especially metallic) below -7°C should be avoided, as should skin contact when handling evaporative liquids (gasoline, alcohol, cleaning fluids) below 4°C.

Sitting or standing still for prolonged periods should be avoided. Alcohol should not be consumed in cold environments as it causes rapid loss of body heat and thus increases the risk of hypothermia. For warming purposes, hot non-alcoholic beverages or soup are suggested. Coffee drinking should be limited because it increases urine production and blood circulation. Both effects result in an increased loss of body heat. Balanced meals and adequate liquid intake are essential to the production of body heat and the prevention of dehydration.

In refrigerated rooms, the air speed should not exceed 1 meter per second. If workers are simultaneously exposed to vibration and/or toxic substances, reduced limits for cold exposure may be necessary.

Surveillance and monitoring

Every workplace where the temperature may fall below 16°C should be equipped with a suitable thermometer to monitor any further temperature changes. For colder workplaces with temperatures below the freezing point, the temperature should be monitored at least every 4 hours. For indoor workplaces, whenever the rate of air movement exceeds 2 meters per second (5 miles per hour) it should be recorded every 4 hours. In outdoor workplaces with air temperature below the freezing point, both air temperature and wind speed should be recorded.

Emergency procedures

Procedures for providing first aid and obtaining medical care should be clearly outlined. For each shift, at least one trained person should be assigned the responsibility of attending to emergencies.

Education

Workers and supervisors involved with work in cold environments should be informed about symptoms of cold strain and cold injury, measures of environmental conditions, proper clothing habits, safe work practices, physical fitness requirements for work in cold, and emergency procedures in case of cold injury.

7. SUMMARY

Work in extreme cold presents a potential health hazard. The feeling of cold is a combined effect of air temperature and wind speed. The effects of cold increase as wind speed increases.

Uncomfortably cold working conditions could lead to reduced work efficiency and higher accident rates. Cooling of body parts may result in cold injuries such as frostbite, frostnip and trenchfoot. Extremities can become frostbitten even while the rest of the body remains sufficiently warm because the blood supply is relatively poor in these body parts. The most severe cold injury is hypothermia, which occurs as a result of excessive loss of body heat and the consequent lowering of the inner core temperature. If immediate medical attention is not provided, hypothermia can be fatal.

Hypothermia and other cold injuries can be prevented by wearing sufficient winter clothing including head protection, gloves, mittens and insulated boots. It is important that all clothing remain dry. Loose, layered clothing provides better protection from cold because of the added insulating properties of air trapped within the layers.

Periodic exercise helps keep the extremities warm. However, once limbs are frostbitten, exercise could result in increased damage. The preferred treatment is slow warming of affected parts. Workers should be educated to identify signs of cold injuries and instructed in methods of providing emergency care to affected co-workers.

APPENDIX A

Table 1 - Equivalent chill temperature (ECT) for various combinations of air temperature and wind speed

Wind velocity km/h	Wind velocity mph		Ambient Temperature								
		°F	40	30	20	10	0	-10	-20	-30	-40
		°C	4	-1	-7	-12	-18	-23	-29	-34	-40
			Equivalent temperatures in still air								
Calm		°F	40	30	20	10	0	-10	-20	-30	-40
0	0	°C	4	-1	-7	-12	-18	-23	-29	-34	-40
		°F	37	27	16	6	-5	-15	-26	-36	-47
8	5	°C	3	-3	-9	-14	-21	-26	-32	-38	-44
		°F	28	16	4	-9	-24	-33	-46	-58	-70
16	10	°C	-2	-9	-16	-23	-30	-35	-43	-50	-57
		°F	22	9	-5	-18	-32	-45	-58	-72	-85
24	15	°C	-6	-13	-20	-28	-36	-43	-50	-58	-65
		°F	18	4	-10	-25	-39	-53	-67	-82	-96
32	20	°C	-8	-16	-23	-32	-39	-47	-55	-63	-71
		°F	16	0	-15	-29	-44	-59	-74	-88	-104
40	25	°C	-9	-18	-26	-34	-42	-51	-59	-67	-76
		°F	13	-2	-18	-33	-48	-63	-79	-94	-109
48	30	°C	-16	-19	-22	-36	-44	-53	-62	-70	-78
		°F	11	-4	-20	-35	-51	-67	-82	-98	-113
56	35	°C	-11	-20	-29	-37	-46	-55	-63	-72	-81
		°F	10	-6	-21	-37	-53	-69	-85	-100	-116
64	40	°C	-12	-21	-29	-38	-47	-56	-65	-73	-82

Source: American Conference of Governmental Industrial Hygienists (ACGIH). Threshold Limit Values (TLVs) and Biological Indices for 1986-1987. p. 76

APPENDIX B

Table 2 - Work/warm-up schedule for four-hour shift and moderate to heavy work activity

Air Temperature Sunny Sky °C	No Noticeable Wind		8 km/h Wind		16 km/h Wind		24 km/h Wind		32 km/h Wind	
	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks
-26°C to -28°C	(Normal)	1	(Normal)	1	75 mins.	2	55 mins.	3	40 mins.	4
-29°C to -31°C	(Normal)	1	75 mins.	2	55 mins.	3	40 mins.	4	30 mins.	5
-32°C to -34°C	75 mins.	2	55 mins.	3	40 mins.	4	30 mins.	5	Non-emergency work should cease	
-35°C to -37°C	55 mins.	3	40 mins.	4	30 mins.	5	Non-emergency work should cease			
-38°C to -39°C	40 mins.	4	30 mins.	5	Non-emergency work should cease					
-40°C to -42°C	30 mins.	5	Non-emergency work should cease							
-43°C and below	Non-emergency work should cease									

This schedule applies to moderate-to-heavy work with breaks of 10 minutes in a warm location. For light-to-moderate work (little physical movement), apply the schedule one step lower. For example, at -35°C with no noticeable wind, a worker at a job with little physical movement should have a maximum work period of 40 minutes with 4 breaks in a 4-hour shift instead of 55 minute work periods and 3 breaks.

APPENDIX C

Glossary of Terms

Acclimatization - The development of resistance to, or tolerance for, an environmental change.

Anemometer - An instrument for measuring wind speed.

Cold strain - Physiological and behavioural responses of the body as a result of exposures to cold.

Cold stress - Disruption of the body's thermal balance due to exposure to cold.

Convection - Process of heat loss by contact with surrounding air or fluid.

Core temperature - Temperature of the inner parts of the body usually determined by measuring rectal temperature.

Dehydration - Loss or deficiency of water in body tissues. The condition may result from inadequate water intake and/or excessive removal of water from the body; for example by sweating, vomiting or diarrhea. Symptoms include a great thirst, nausea, and exhaustion.

Equivalent chill temperature - Still air temperature that would have the same cooling effect on human flesh as a given combination of temperature and wind speed.

Frostbite - Damage resulting from exposure to extremely low temperatures, involving not only the skin and underlying tissue but also deeper tissues, sometimes leading to gangrene and loss of affected parts.

Frostnip - Cold injury of ear lobes, nose, cheek, fingers and toes resulting from exposure to low temperatures, involving only the skin or extending to the tissue immediately beneath it. It may cause simple reddening of the skin and temporary loss of sensation.

Gangrene - Local death of soft tissues due to loss of blood supply.

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Hypothermia - Reduction of body temperature below normal range.

Immersion foot - Damage to the toes and the skin of the foot due to death of the superficial tissues and caused by prolonged exposure to cold damp conditions.

kcal - Quantity of heat required to raise the temperature of 1 kilogram water by 1°C.

Metabolic rate - Rate of energy production of the body. It varies with the level of physical activity.

Raynaud's disease - A condition resulting in reduced blood circulation and a sense of cold in the hands which can be caused by exposure to hand/arm vibration.

Relative humidity - The ratio of the amount of water vapour actually present in the air to the maximum amount possible at the same temperature.

Thermometer - Instrument used to measure temperature.

Thermoregulatory system - Sweating and blood circulation organs that respond to maintain constant body temperature in hot and cold working environments.

Trenchfoot - See immersion foot.

Wind-chill temperature - A measure of the combined effects of wind speed and air temperature on exposed human flesh.

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